HOKKAIDO UNIVERSITY

HIGH-RESOLUTION TSUNAMI-BEDLOAD COUPLED COMPUTATION IN AMR ENVIRONMENT

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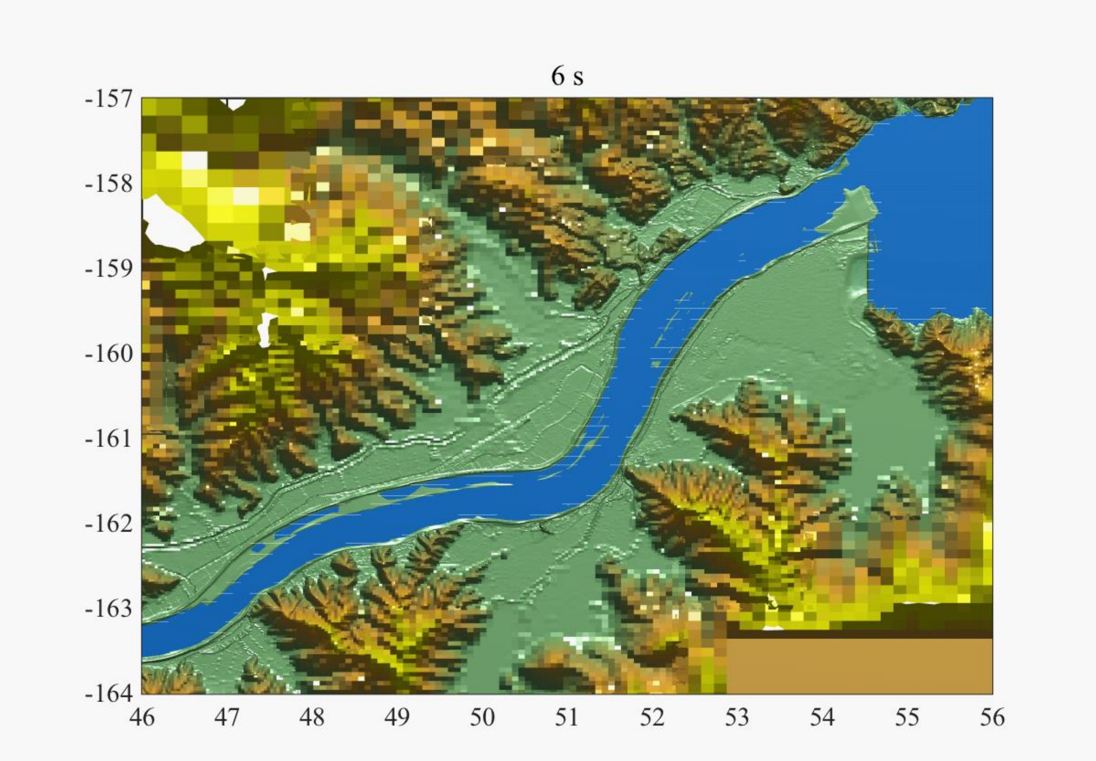
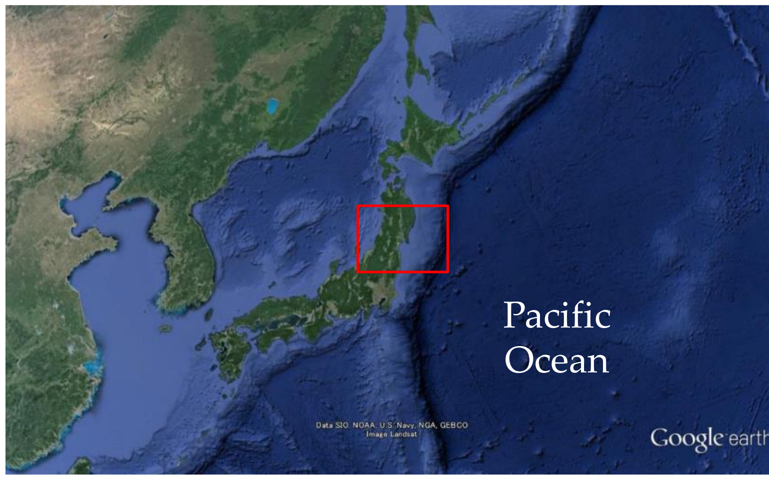
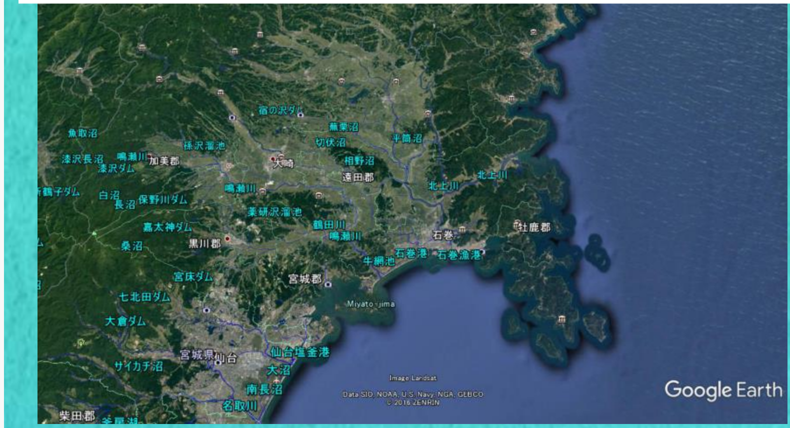
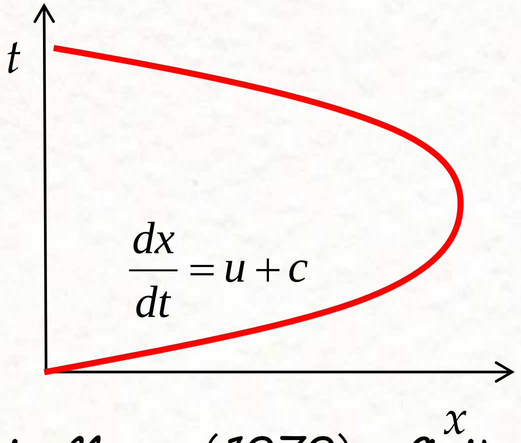


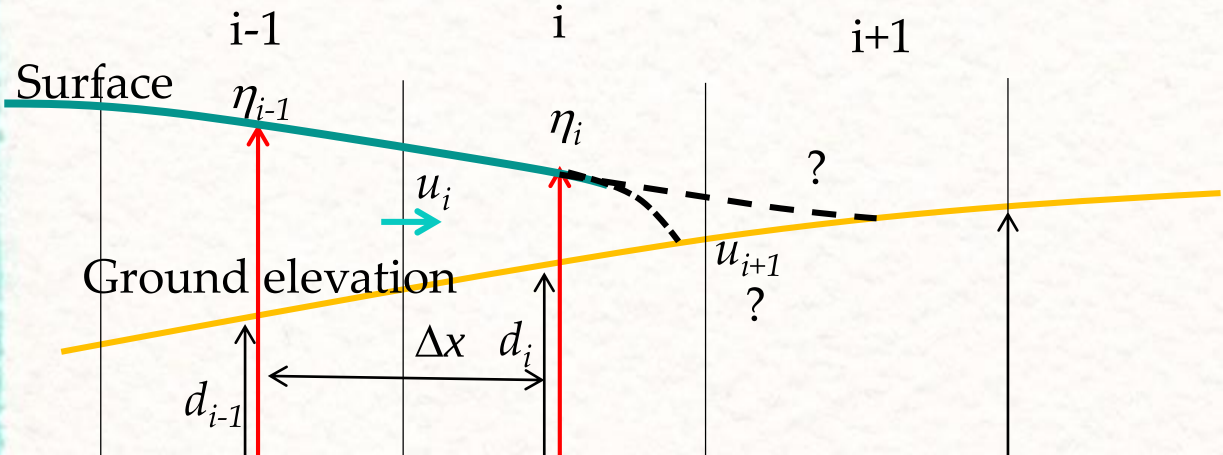




- *Tsunami computation in Adaptive Mesh Refinement environment (Watanabe et al 2010, Watanabe et al 2012)*
- *Shen & Meyer (1963); wave runup by characteristic curve*



- *Iwasaki, Mano (1979) :finite difference for NSWE →uncomputable near the front→undefined the front location*



Objective

New framework of semi-Lagrangian runup computation coupled with Bedload sediment transport model

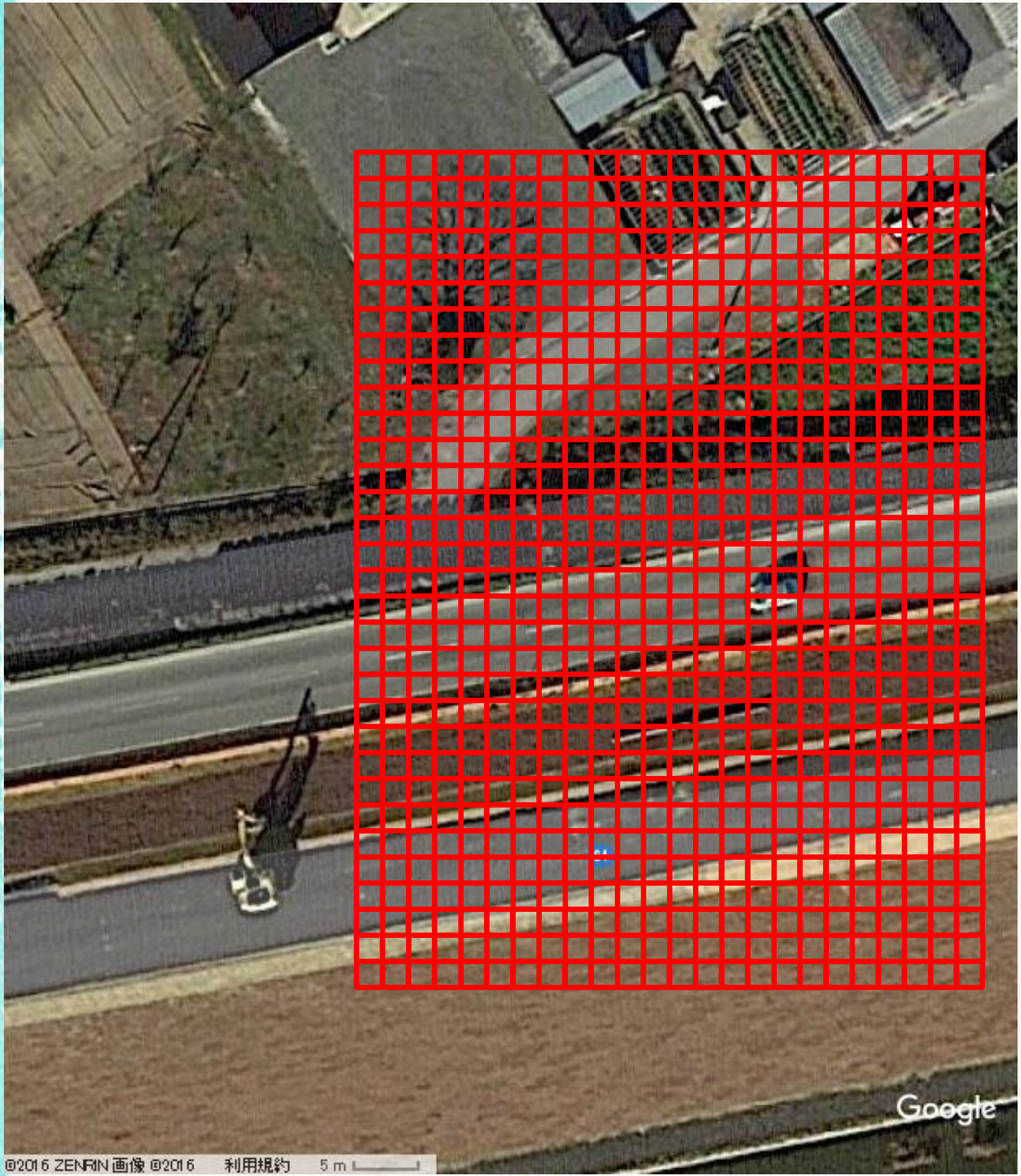
Effects of resolution to computed results

Resolution

Equivalent roughness
(land use, vegetation)

Structures (dike, tide wall)

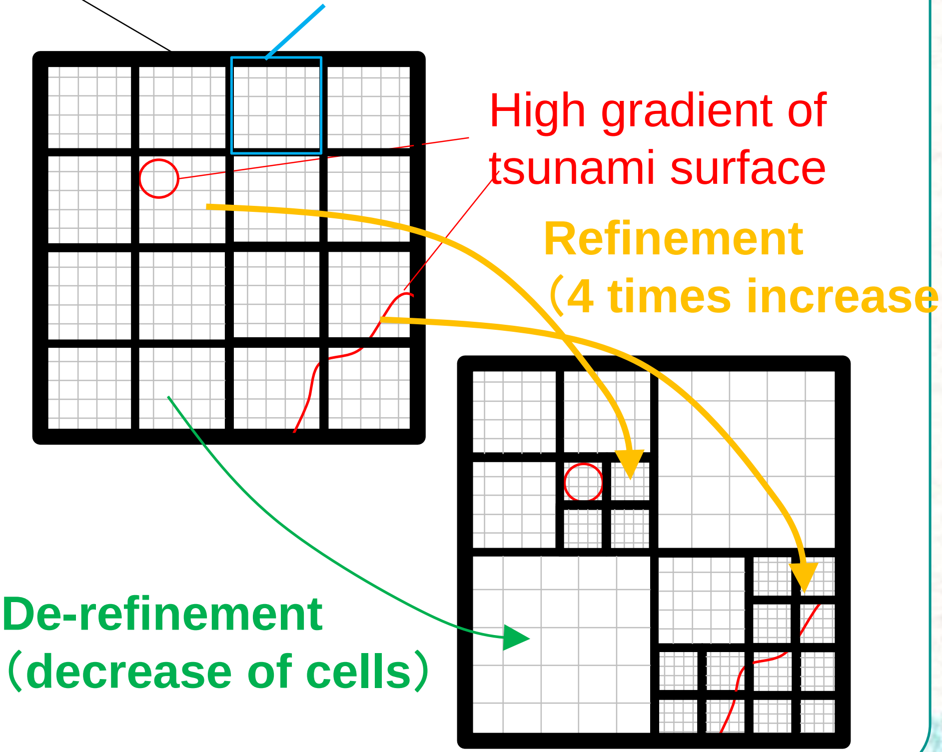
friction→drag force



AMR (Adaptive Mesh Refinement)

Dynamic refinement of local computing cells to perform high-resolution computation at low cost

Cell refinement and de-refinement



Domain

Computing Block（10 x 10cells)

High gradient of tsunami surface

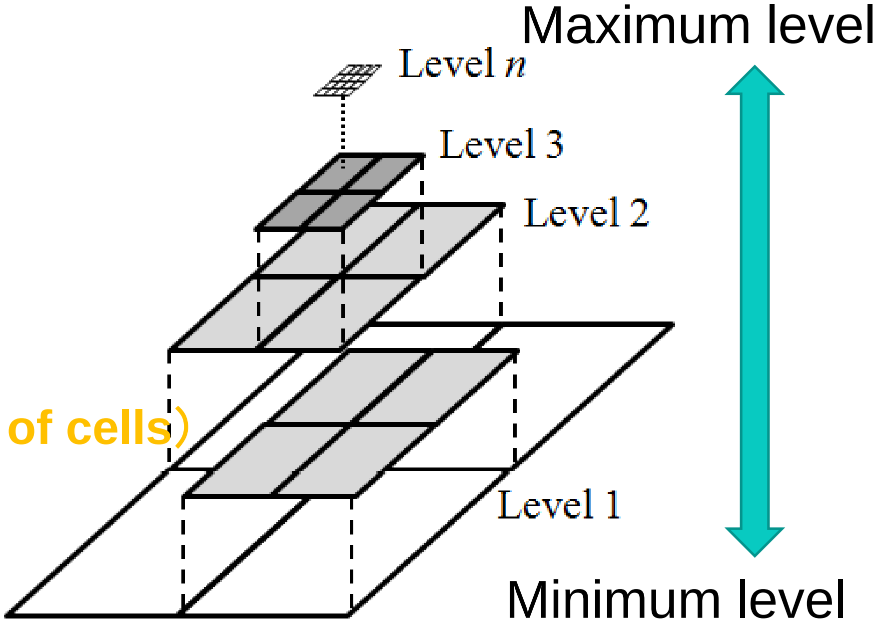
Refinement

（4 times increase of cells）

De-refinement

（decrease of cells）

Quadtree refinement level



Maximum level

Minimum level

Flows with wide ranging length scales can be efficiently computed at optimum resolution!

AMR-CIP runup model for high resolution land elevation data

2m lp data →Resolve major facilities and structures

Comprehensive runup computation without dry / wet condition at the front

Nonlinear Shallow Water equation

$$\frac{\partial \boldsymbol{u}}{\partial t} + (\boldsymbol{u}\nabla)\boldsymbol{u} = -g\nabla\eta + \nu_h \nabla^2 \boldsymbol{u} + \boldsymbol{\tau_b}$$

$$\frac{\partial \eta}{\partial t} + \nabla \cdot \big(\boldsymbol{u}(h+\eta)\big) = 0$$

$$\boldsymbol{u}^* = \boldsymbol{u}^n - \Delta t g \nabla \eta^n + \Delta \nu_h \nabla^2 \boldsymbol{u}^* + \boldsymbol{\tau_b}$$

$$\eta^* = \eta^n - \Delta t(\nabla \cdot (\boldsymbol{u}^n h) + \eta^n \nabla \cdot \boldsymbol{u}^n)$$

Fractional step method

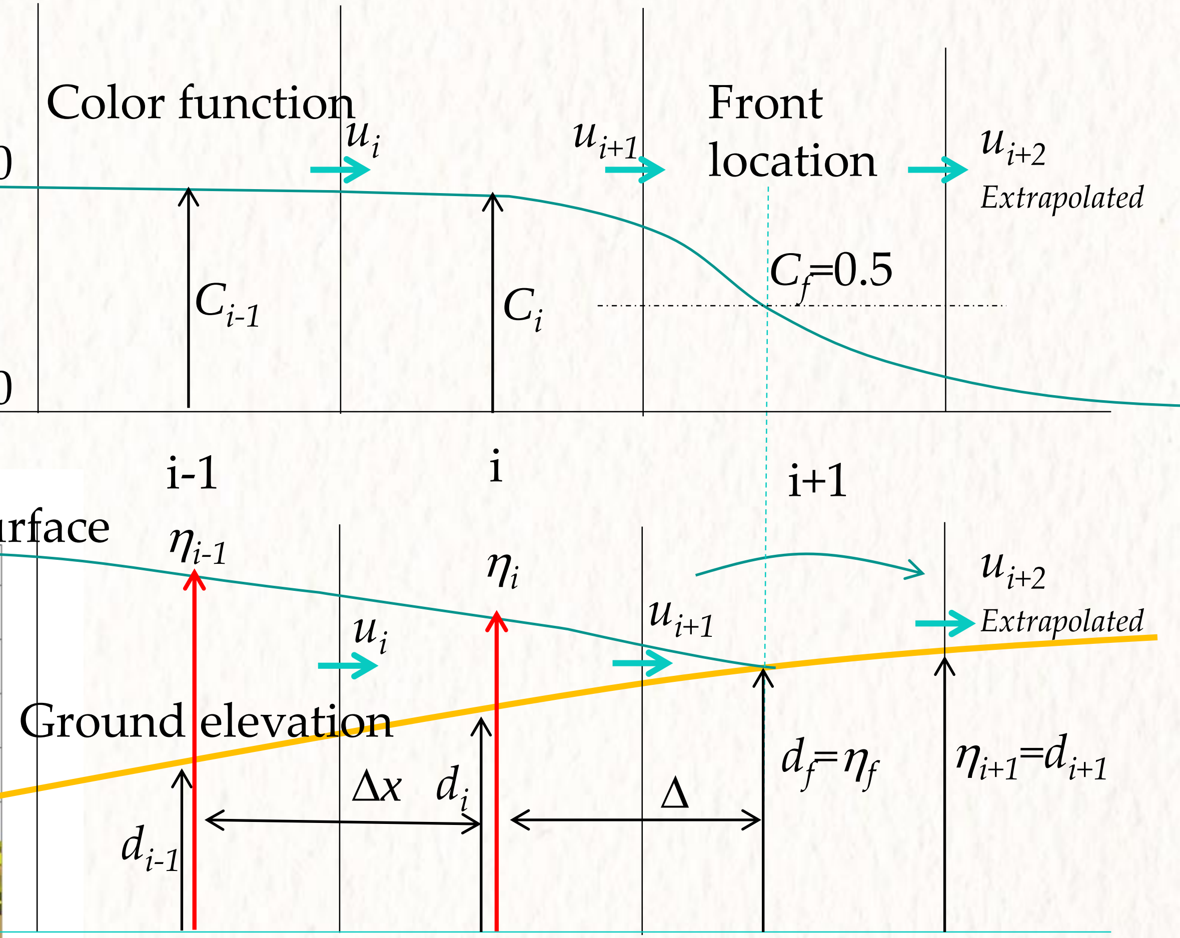
$$\frac{D\boldsymbol{u}^*}{Dt} = 0 \qquad \frac{D\eta^*}{Dt} = 0 \qquad \frac{DC}{Dt} = 0$$

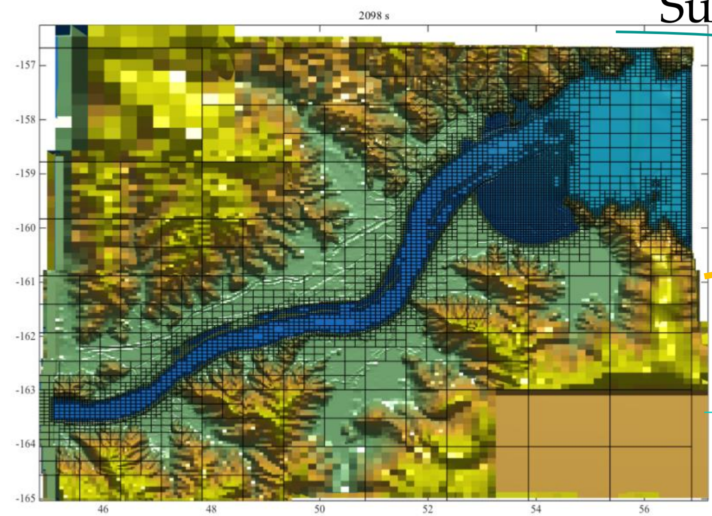
Cubic Interpolation Profile (CIP) method

Semi-Lagrangian approach for runup front
Color function to define the front location
|C-Cf| to be the condition for grid refinement
→Capturing the front location at high resolution

$$\frac{DC}{Dt} = 0$$

C=1 Fluid
C=0 Out of fluid
C=0.5 Front location





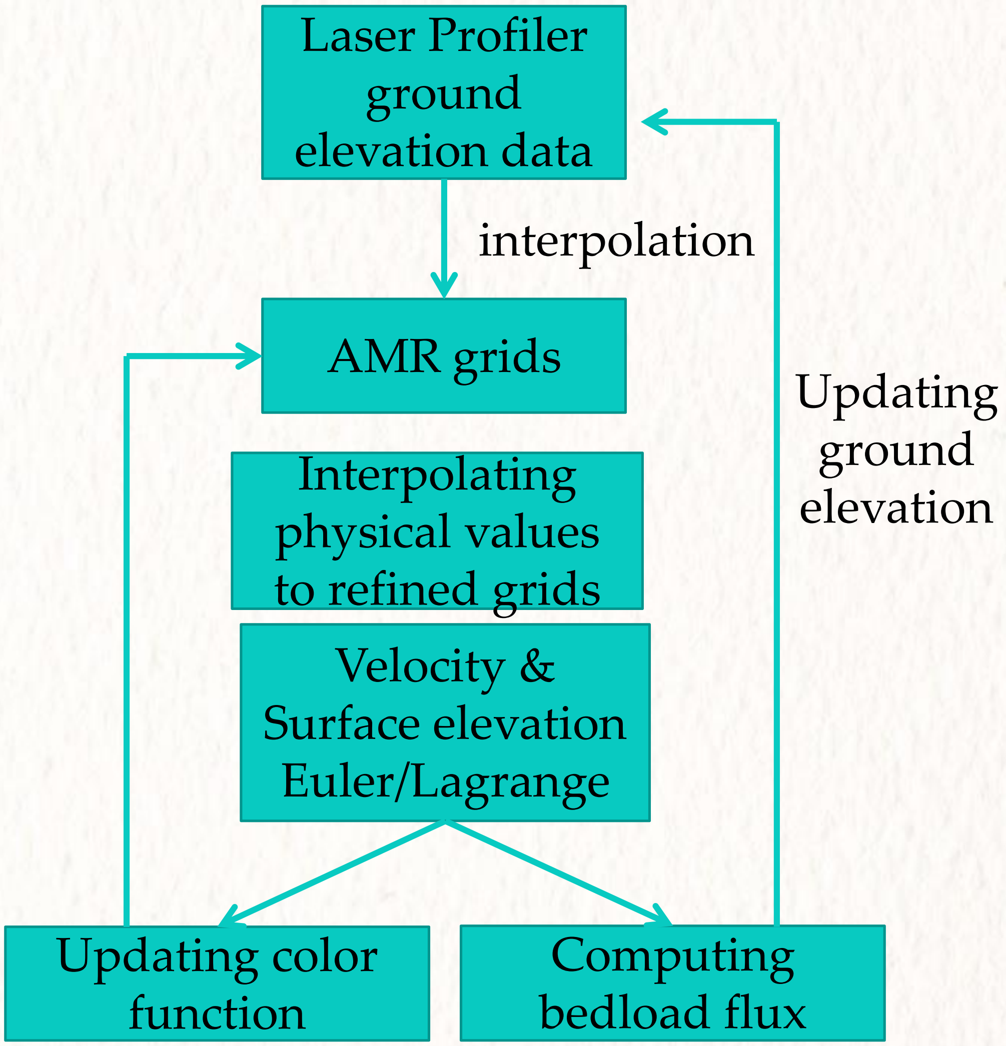
Meyer-Peter-Muller

$$\boldsymbol{q}_{b0} = 8\sqrt{\left(\frac{\rho_s}{\rho}-1\right) g d^3}\left(|\boldsymbol{\theta}| - \theta_c\right)^{3/2}\frac{\boldsymbol{\theta}}{|\boldsymbol{\theta}|}$$

$$\boldsymbol{q}_b = \boldsymbol{q}_{b0} - \alpha|\boldsymbol{q}_{b0}|\nabla z$$

$$\frac{\partial z}{\partial t} + \frac{1}{1-\lambda}\nabla\cdot\boldsymbol{q}_b = 0$$

Specific gravity of sand:1.67
Particle size of sand: 0.000267
Critical Shields Parameter: 0.03
Porosity: 0.4



Laser Profiler ground elevation data

interpolation

AMR grids

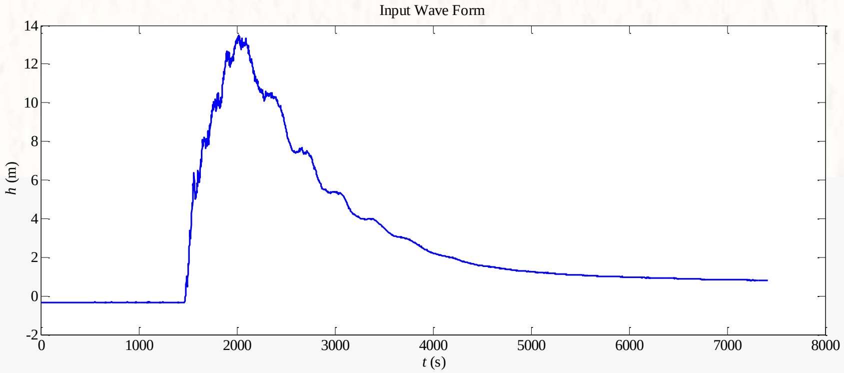
Interpolating physical values to refined grids

Velocity & Surface elevation Euler/Lagrange

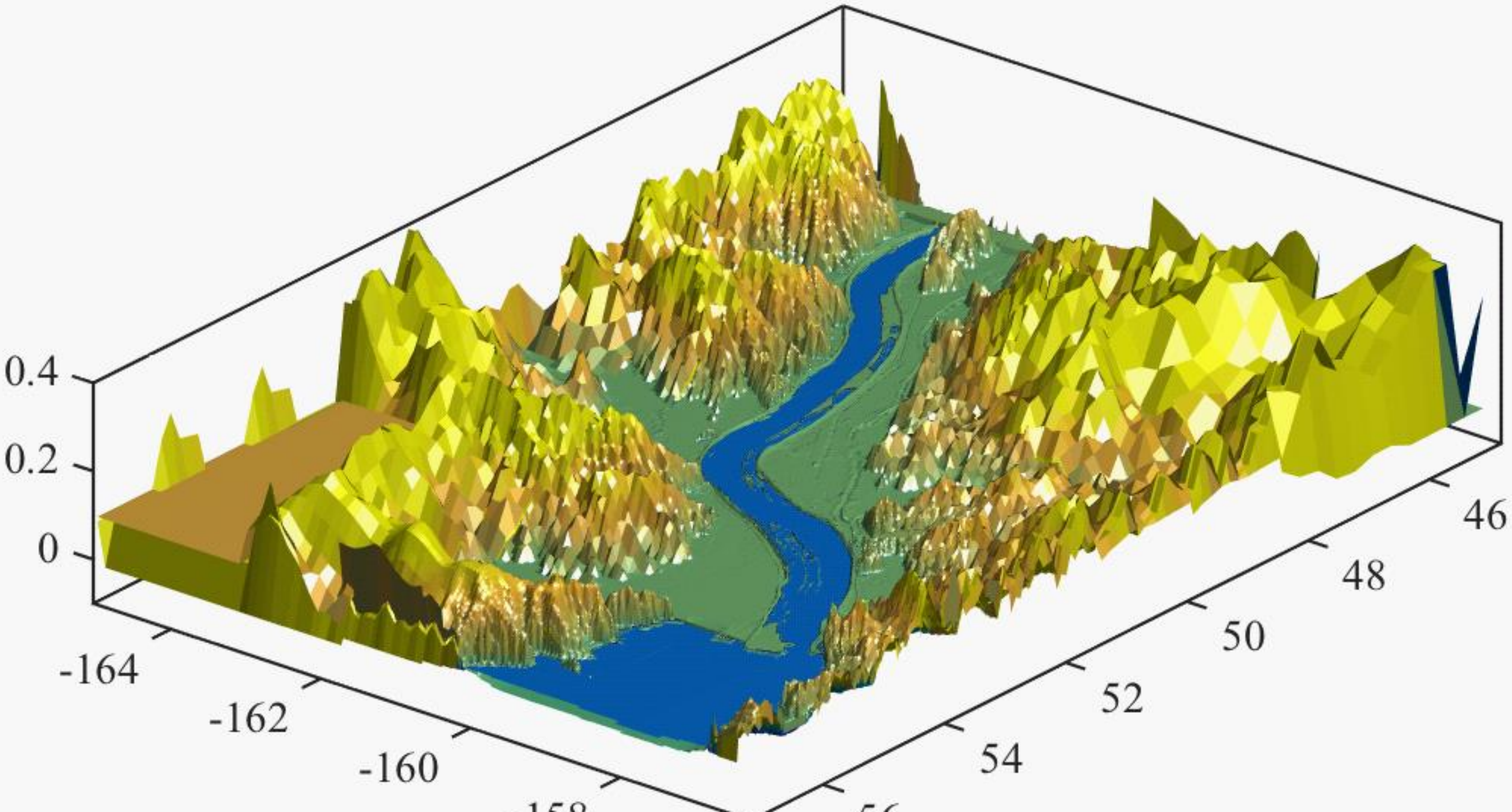
Updating color function

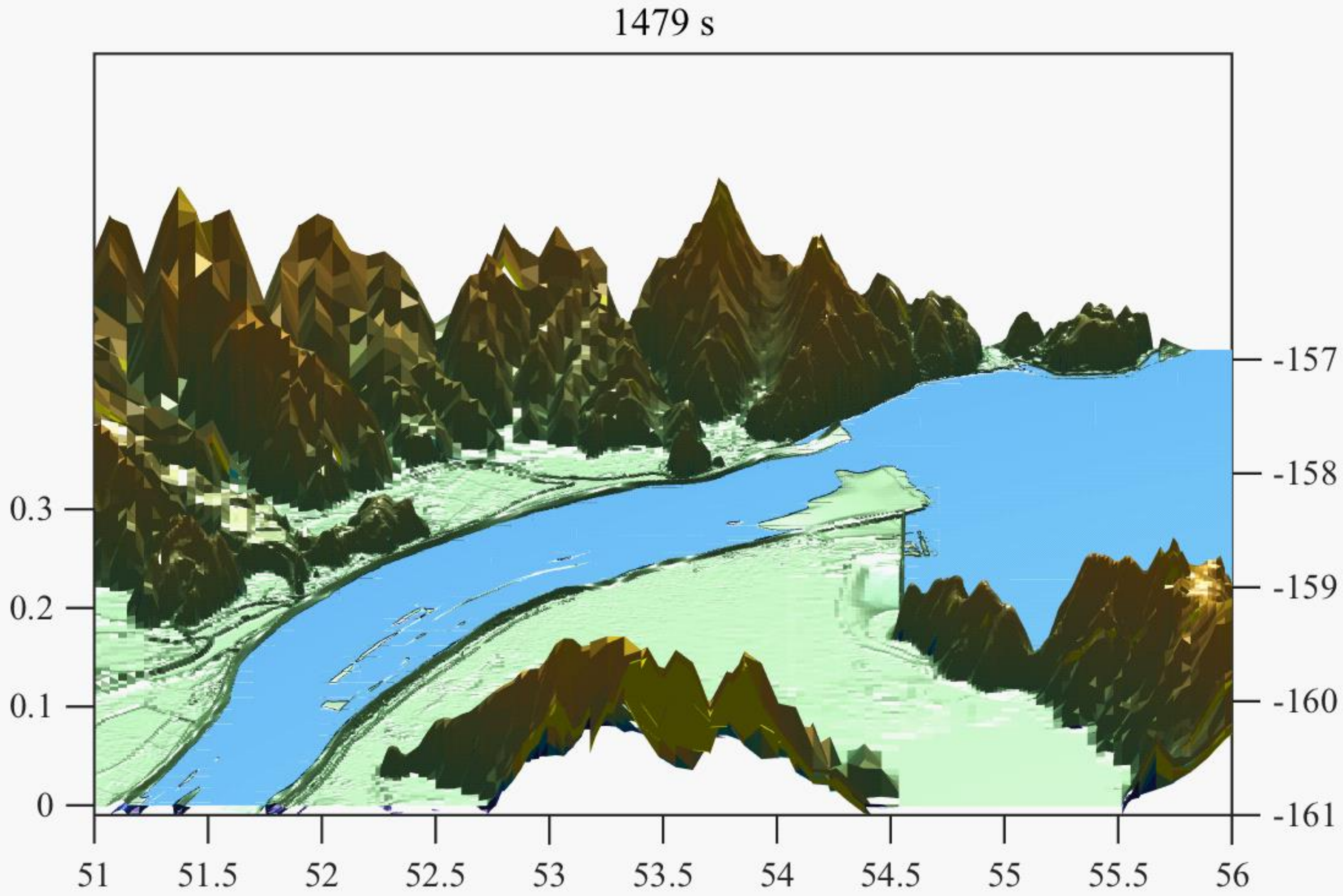
Computing bedload flux

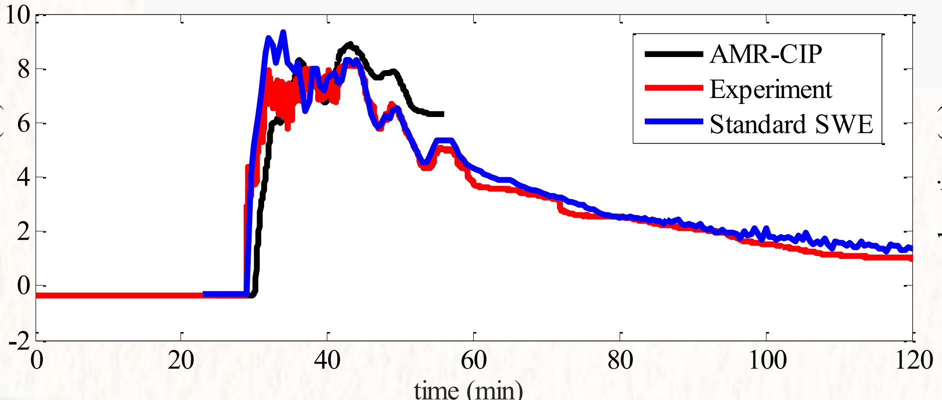
Updating ground elevation

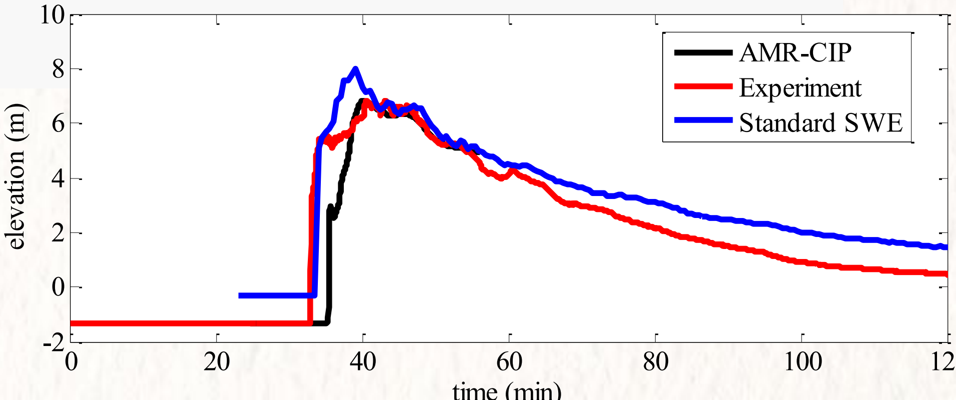

Input Wave Form

Laboratory Experiment (fixed bed)
Refinement level 9
Maximum resolution of 1·2 m


1479 s

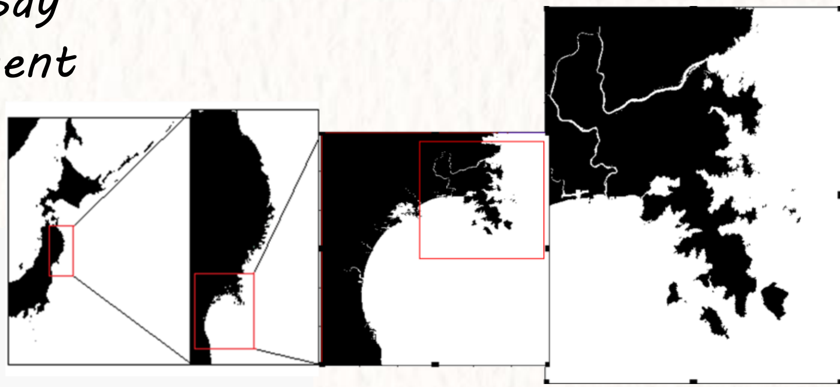

1479 s
0.3
0.2
0.1
0
-157
-158
-159
-160
-161
51
51.5
52
52.5
53
53.5
54
54.5
55
55.5
56


AMR-CIP
Experiment
Standard SWE
10
8
6
4
2
0
-2
0
20
40
60
80
100
120
time (min)

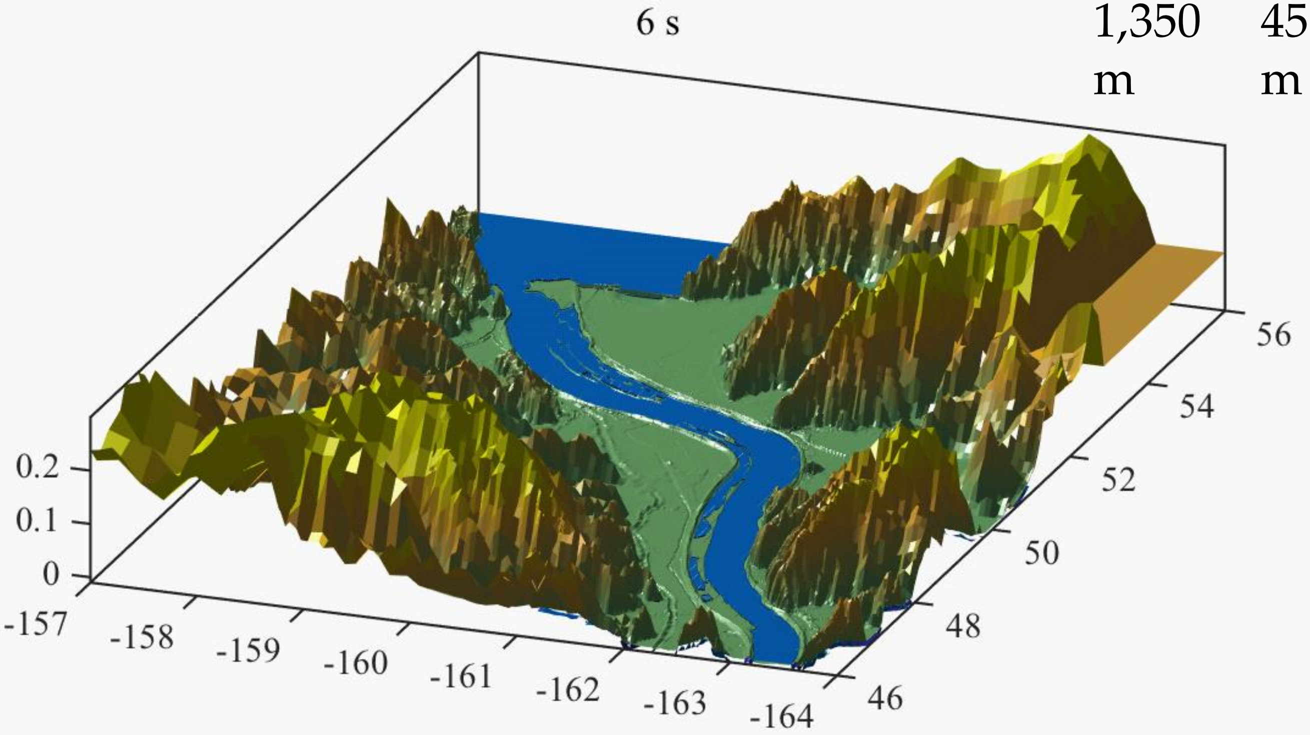

AMR-CIP
Experiment
Standard SWE
elevation (m)
10
8
6
4
2
0
-2
0
20
40
60
80
100
120
time (min)

In-situ Computation

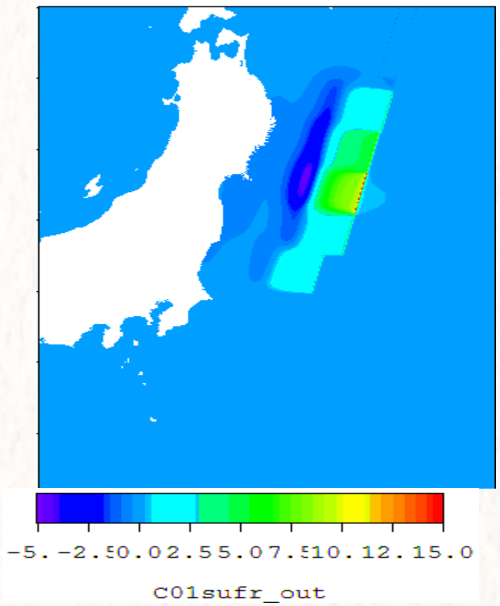
- Ocean tsunami computation result as a boundary condition at offshore end of Oppa Bay
- 2-m land elevation data (maximum refinement level 9, maximum resolution 1.2m)
- mobile bed case



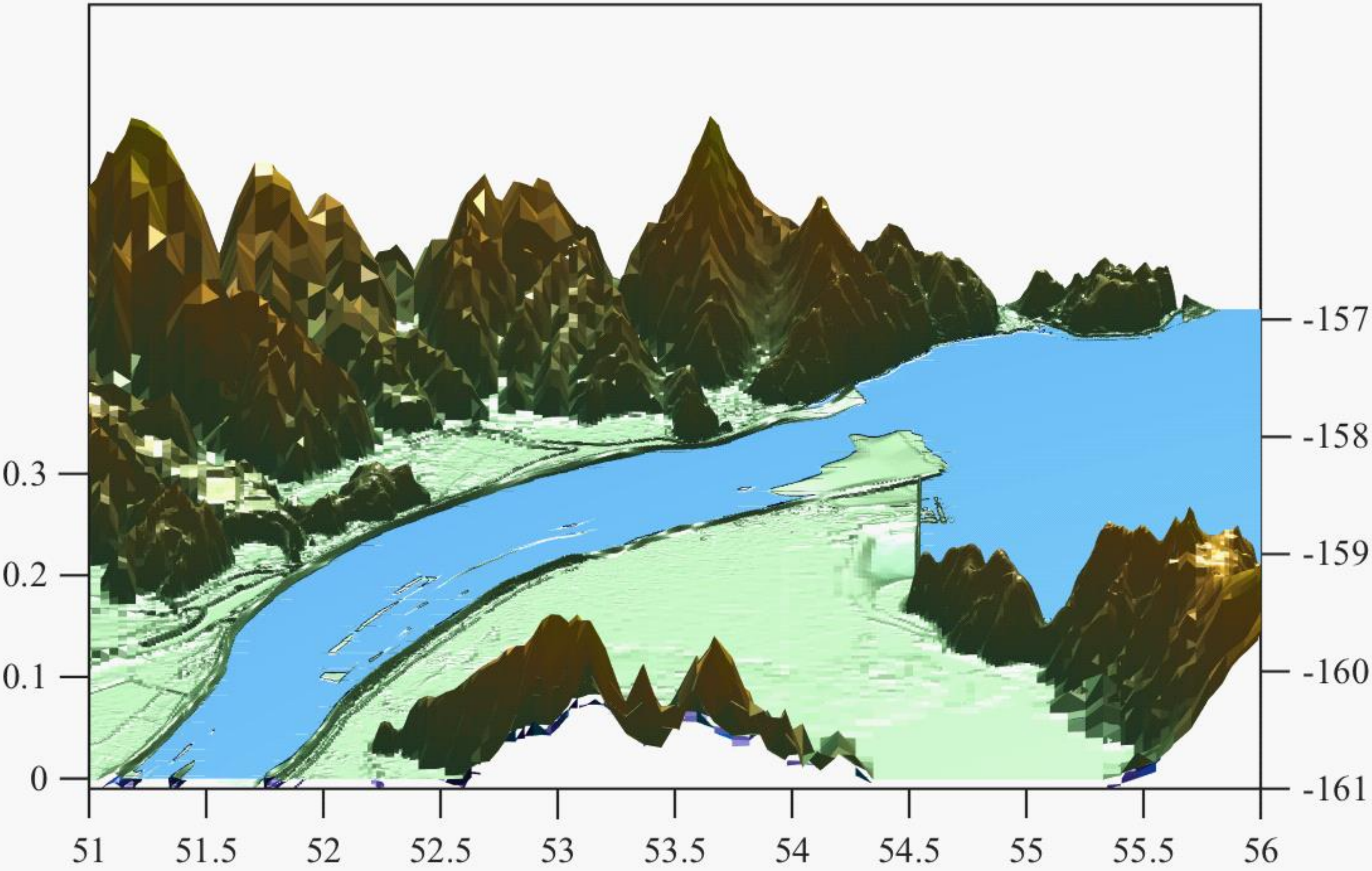
1,350 m 450 m 150 m 50m

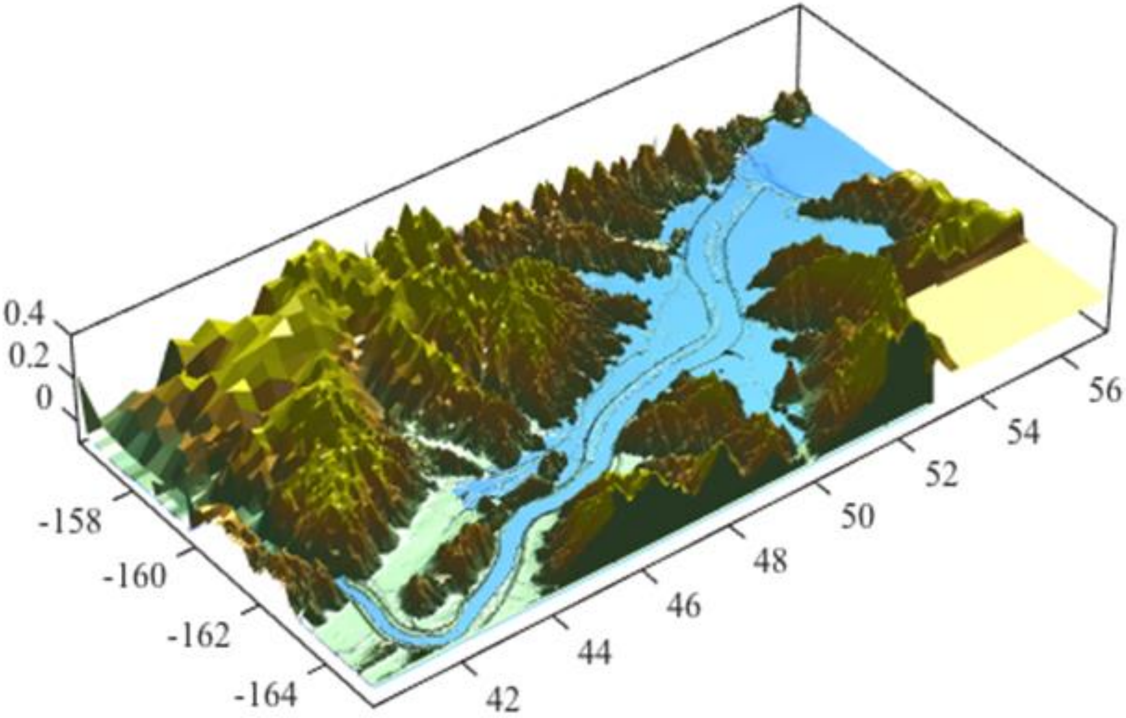


Tsunami source



6 s





Inundation area

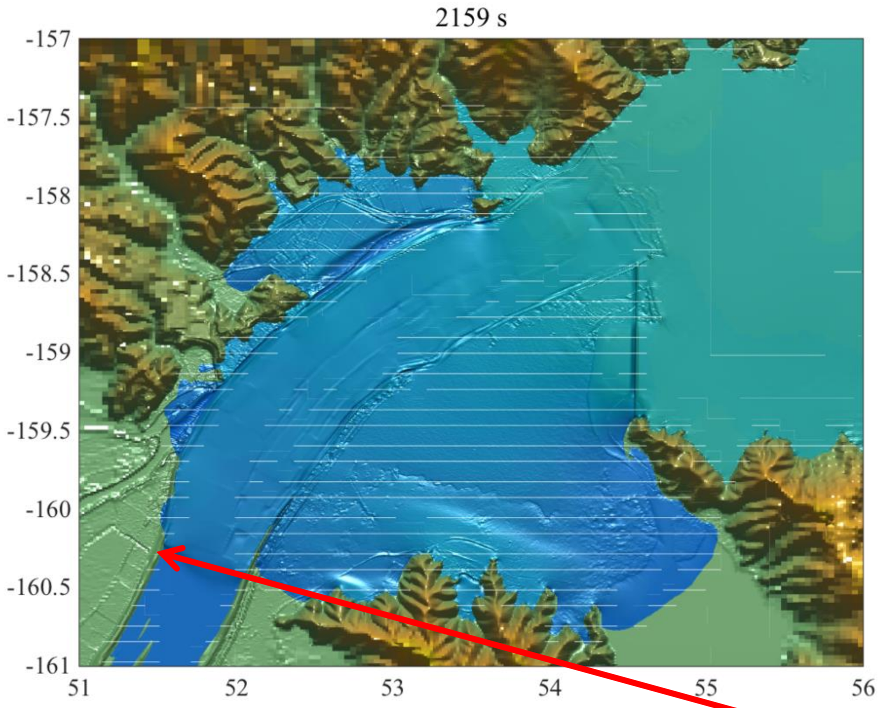
AMR (2m LPdata, 1.2m resolution

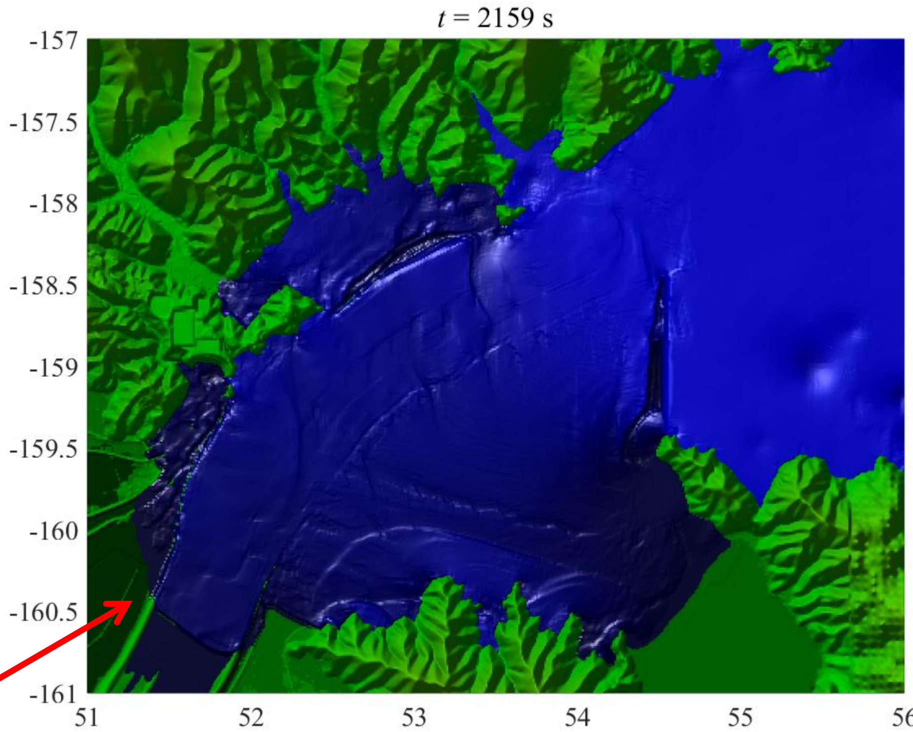
Conventional model (10m LPdata, 10m resolution

Differences in flooding velocity on canals and roads (with variations of ground elevation)

Differences in flooding velocity on canals and roads (with variations of ground elevation)

AMR→shape resistance is explicitly computed →reduced flooding velocity





Differences in timing and location of overflow

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⇒ may depend on resolution!

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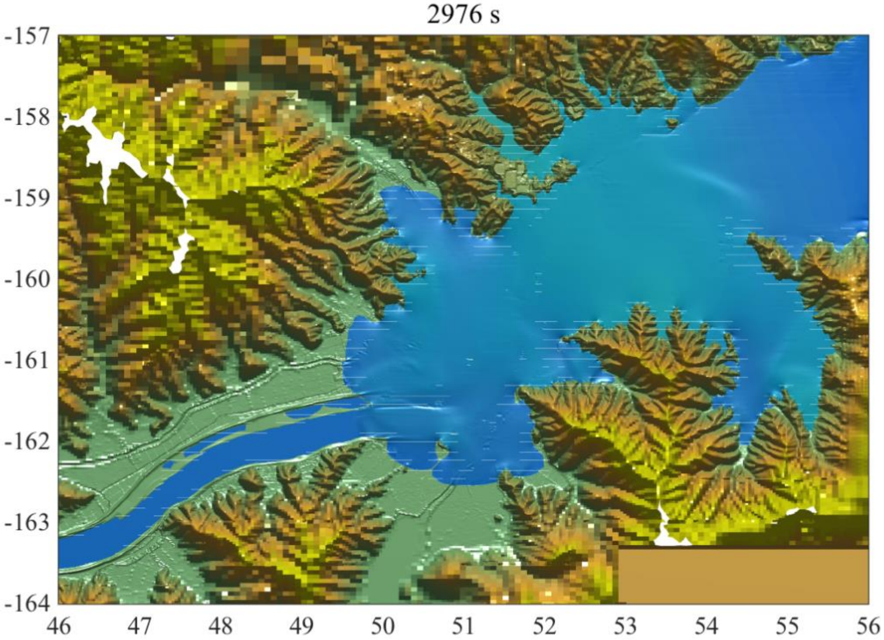
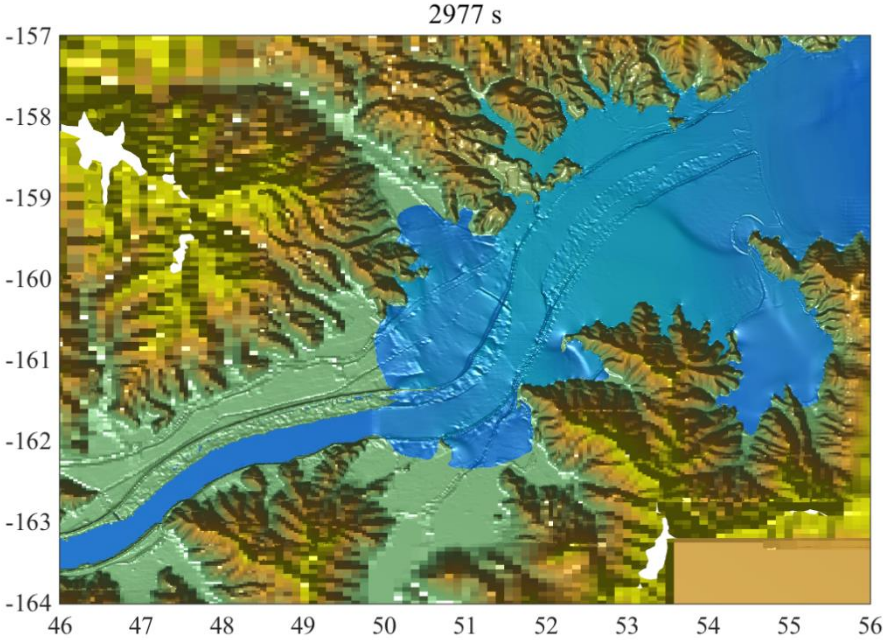
Identical flooding process on even ground level

AMR (2mLP data, 1.2m resolution)



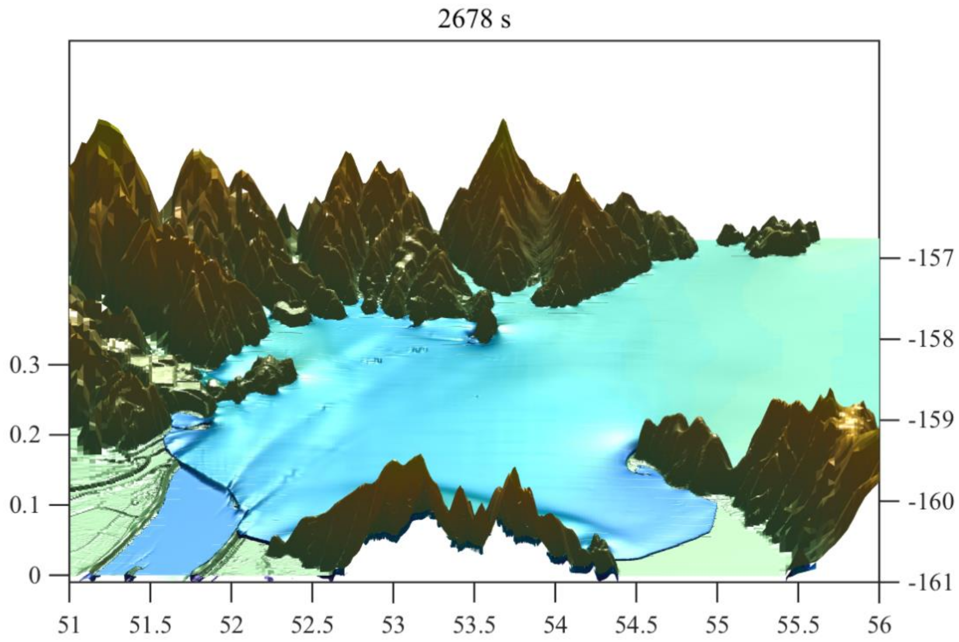
AMR (10mLP data, 2.4m resolution)



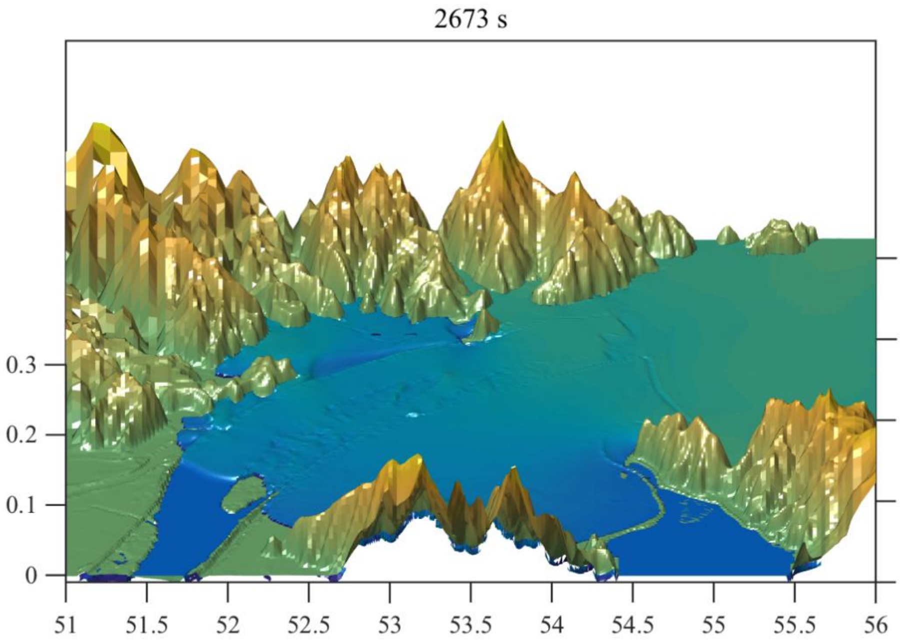
Identical flooding process

Slight difference in flooding velocity
←Faster Erosion of embankment

AMR (2mLP data, 1.2m resolution)

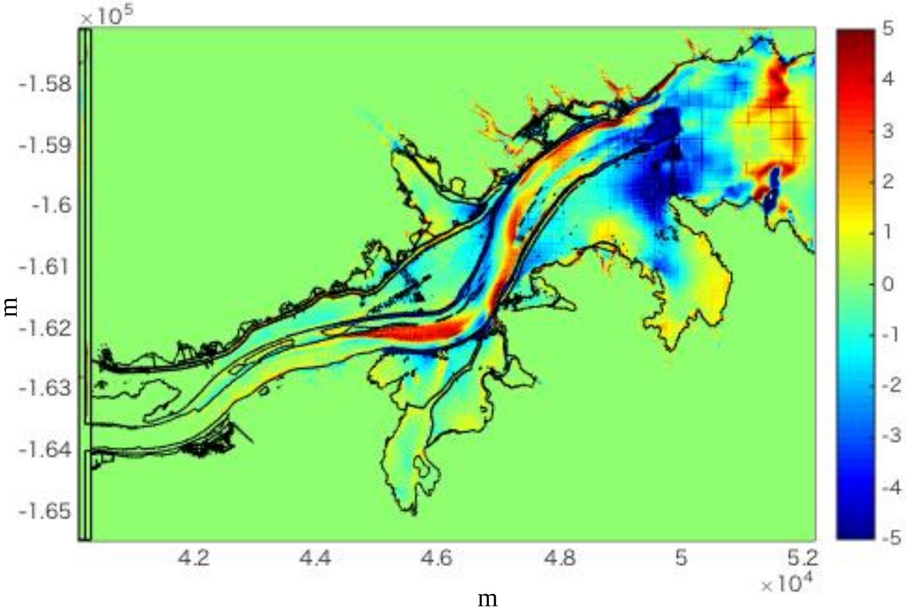


AMR (10mLP data, 2.4m resolution)

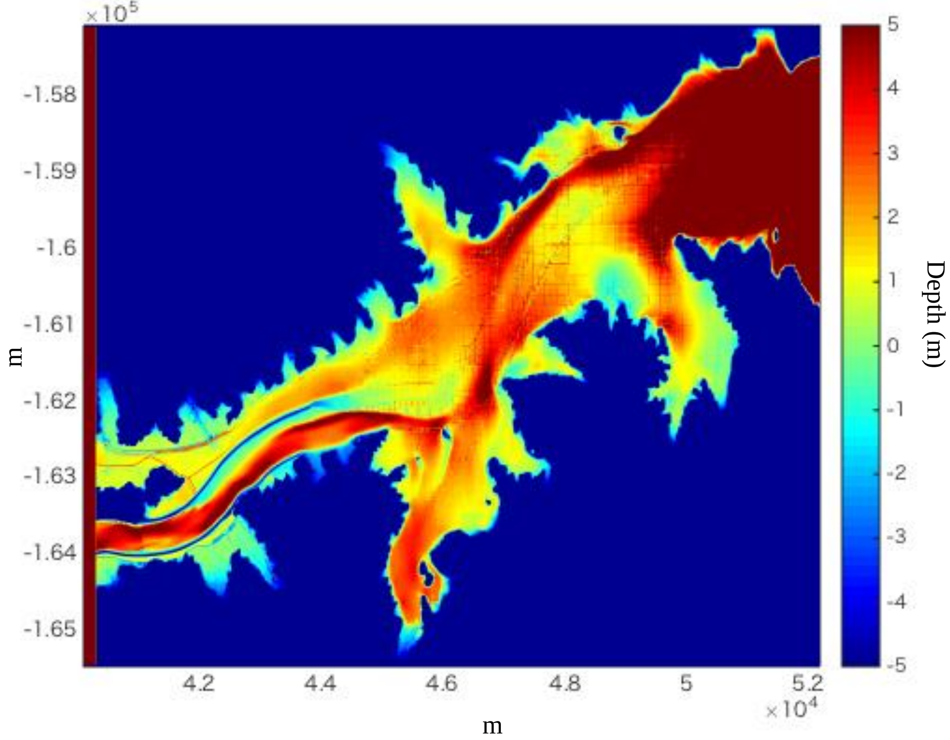


Resolving the sharp wave front
→sharp gradient of shear stress→high gradient of
bedload flux→local erosion

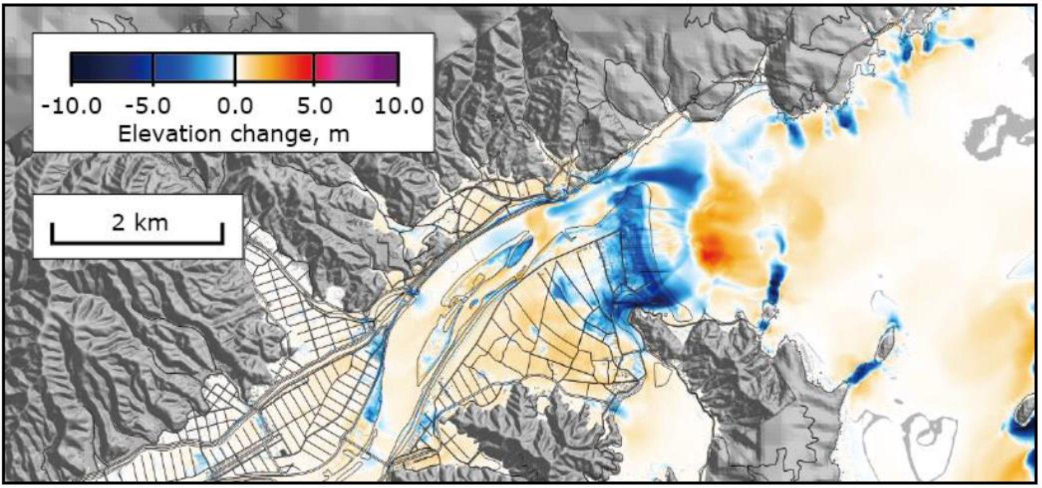
$$\frac{\partial z}{\partial t} + \frac{1}{1-\lambda} \nabla \cdot \boldsymbol{q}_b = 0$$



Displacement of ground level due to tsunami



Land elevation after the flood



Observation by Imai et al. (2015)

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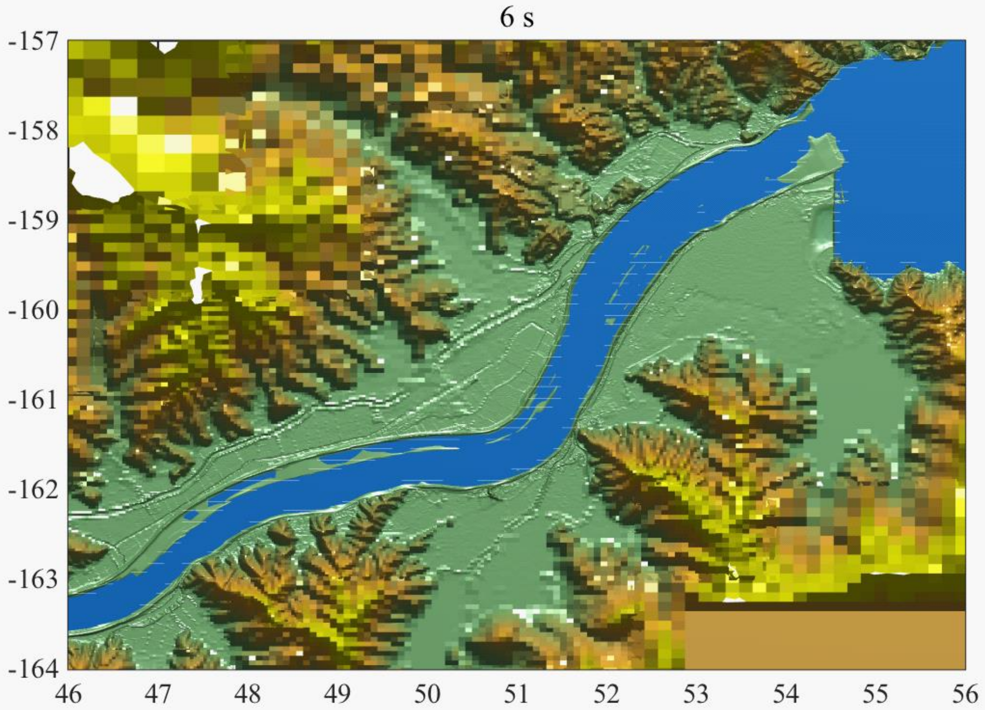

New framework of tsunami runup

Resolution is unimportant for estimating the maximum inundation area.

Resolution is important for estimating ground erosion.